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Selection of opponents in the prisoner's dilemma in dynamic networks: An experimental approach

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HIGHLIGHTS

- We study the Prisoner's Dilemma in dynamic networks.
- We conducted a laboratory experiment to explore how humans select neighbors.
- A subject who has more neighbors is less likely to dismiss links.
- A subject is more likely to create links to select opponents who have more neighbors.

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ABSTRACT

To investigate how a human subject selects her neighbors (opponents) to play the Prisoner's Dilemma within a social network, we conducted a human-subject experiment. The results are as follows: (1) A subject is more likely to dismiss the links to her neighbors most frequently when the subject chooses *C* and when the neighbor chooses *D*; (2) a subject who has more neighbors is less likely to dismiss links than a subject who has fewer neighbors; and (3) a subject is more likely to create links to (=select) opponents who have more neighbors than to opponents who have fewer neighbors.

1. Introduction

The issue of the evolution of cooperation has been discussed using the Prisoner's Dilemma (PD) game in various fields such as biology (Hamilton, 1964; Brauchli et al., 1999; Ohtsuki et al., 2006; Pacheco et al., 2006a; Wu et al., 2010; Fehl et al., 2011), management (Hanaki and Peterhansl, 2007), physics (Santos and Pacheco, 2005; Zimmermann and Eguíluz, 2005; Pacheco et al., 2006b; Fu et al., 2007), and economics (Fundenberg and Maskin, 1990; Young and Foster, 1991; Andersen, 2004).[1] The PD is a game where two individuals choose their action from cooperation (*C*) or defection (*D*), and it is best for each individual to defect regardless of the opponent's choice. If we assume a population where everybody is equally likely to play the PD with everybody else (the PD in a well-mixed population) and higher average-score individuals leave more offspring in later generations (survival of the fittest), as in standard evolutionary game models, defectors eventually dominate the population through the evolutionary process. However, cooperative behaviors are ubiquitous in the real world, ranging from biological systems to socioeconomic systems (Fu et al., 2007). What sort of mechanism promotes the evolution of cooperation?

Nowak (2006) identified there are five representative mechanisms for the evolution of cooperation: (1) kin selection; (2) direct reciprocity (e.g., tit for tat); (3) indirect reciprocity (reputation); (4) multilevel selection; and (5) network reciprocity. In this study, we focus on network reciprocity.

Network reciprocity is a mechanism that promotes the evolution of cooperation. It works when individuals of a population only interact with a *subset* of the population (*a limited number of neighbors*) because of the limitation by the spatial structure of the network and the limitation of each individual's capacity/resource to interact with others. Although standard evolutionary game theory assumes well-mixed populations, where it is equally likely that everybody interacts with everybody else, structures of social or economic populations in the real world are not always well-mixed. The limitations by the spatial structure and each

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[1] The evolution of cooperation is defined as the emergence, prevalence and preservation of cooperative behaviors in the existing population or society.

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individual's capacity/resource in real populations can be modeled with a networked population where individuals occupy the vertices of a network and interact only with their neighbors in the network.

Many studies that work on network reciprocity show that cooperators can prevail by forming network clusters, where they help each other (Nowak and May, 1992; Brauchli et al., 1999; Santos and Pacheco, 2005). At first, Nowak and May (1992) assumed that each individual only plays the PD with immediate neighbors in a lattice network. Also, in view of the iterated prisoner's dilemma game, Brauchli et al. (1999) studied the evolution of cooperation within the strategy space of all stochastic strategies with a memory of one round. Moreover, because most of social networks seen in the real world are not lattice networks, Santos and Pacheco (2005) assumed that each individual only plays the PD with immediate neighbors in a scale-free network which has a feature of complex networks seen in the real world (Newman, 2003). A scale-free network is a network with a degree distribution that follows a power law at least asymptotically. In these studies, each individual chooses her action from *C* or *D* and initially plays the PD with all her neighbors. However, she then imitates the previous action of the individual whose payoff is the highest among neighbors, including herself, in each period. These studies suppose static networks whose structures do not change with time. However, the structures of social networks in the real world are often dynamic; that is, individuals are continuously creating or dismissing interactions according to the benefits of the relationships.

There are some studies regarding reciprocity in dynamic networks. For example, in theoretical biological fields, Pacheco et al. (2006a) assumed a mathematical model that individuals differ in the frequency of neighbor selections and specified mean field equations governing the so-called active linking dynamics of the network. In addition, using the neighbor selection algorithm characterized by a Markov chain, Wu et al. (2010) analytically showed that the more fragile links between cooperators and defectors are (or the more robust links between cooperators are), the more likely cooperation prevails. Thus, mathematical models are useful for reciprocity in dynamic networks in theoretical biological studies. However, generically, there are limits to what we can study in terms of reciprocity in dynamic networks simply using mathematical models. Thus, there are several simulation studies regarding reciprocity in dynamic networks (e.g., Luthi et al., 2005; Santos et al., 2006; Hanaki and Peterhansl, 2007).[2] For example, in Zimmermann and Eguíluz (2005), Fu et al. (2007), and Tanimoto (2007), each individual not only chooses her action from *C* or *D* (Action choice),[3,4] but also selects a limited number of neighbors (a subset) from the population (Neighbor selection). In addition, these three studies assume that neighbor selection consists of the following two steps: (1) dismissal of links: each individual selects opponents, each of whom she wants to dismiss from the multiple candidates (her current neighbors) herself; and (2) creation of links: after the dismissal of links, she selects as the same opponents, each of whom she wants to create links to as selected for the dismissal of links from the multiple candidates (her current non-neighbors) herself.[5] Furthermore, agents are assumed to play an n-round repeated PD in Fu et al. (2007) and a one-shot PD in the other two studies. These three studies show that the emergence of reciprocal cooperation is possible by the introduction of neighbor selection.

However, the agent models in these studies are not constructed based on the behavioral patterns of human-individuals in the real world. We present the dismissal and creation algorithms used in these representative studies in Table 1. To check whether behavioral patterns of human-individuals in the real world can be approximated using the algorithms in Table 1 and to check whether there are other algorithms that have not been used in Table 1, human-subject experiment studies (where subjects play the PD in dynamic networks) might be useful.

There are human-subject experiment studies where each subject plays the PD in dynamic networks (Rand, 2011; Fehl et al., 2011; Wang et al., 2012).[6] In Rand (2011), each subject either chooses her action from *C* or *D*, initially with all her neighbors. A percentage k (=0, 10, or 30) of subject pairs are then picked at random to have their links updated. If a link already exists between a pair of subjects, one of the two (picked at random) is offered the chance to dismiss the link. If no link exists, one of the two (again picked at random) is offered the chance to create a new link. The result is compared with a well-mixed condition (control condition). In contrast, Fehl et al. (2011) compared cooperative behavior in multiple but independent repeated games between participants in static and dynamic networks. Only in dynamic networks are subjects asked if they want to continue to play with their neighbors (indicated by YES or NO decisions). Afterwards, information is later given to subjects stating whether or not their neighbors wish to continue the relationship. If a linked pair agreed to do so, they are also paired in the following period. If, however, at least one of them refuses to keep playing, the link is dismissed and both receive new neighbors, randomly chosen from all subjects looking for new neighbors at that time point. In addition, based on the results of these two experimental studies, Wang et al. (2012) reported on a human-subject experiment in which each subject selects neighbors after one shot or n-round PD. These three studies also show that in human-subject experiments, reciprocal cooperation can emerge by the introduction of neighbor selection.

However, these studies do not focus on how a human-individual actively selects her neighbors; rather, they show, how the introduction of neighbor selection facilitates the evolution of cooperation. First, the results from Rand (2011) and Fehl et al. (2011) cannot answer the question, "What kind of human-individuals are selected to be dismissed or created links to *from the multiple candidates* in the real world?", because Rand (2011) assumed that a subject can only decide whether or not she will dismiss (create) links to other subjects that the computer selected randomly. In addition, Fehl et al. (2011) assumed that a subject cannot herself select opponents to create

[2] A mini review on reciprocity in dynamic networks is given by Perc and Szolnoki (2010).

[3] In Zimmermann and Eguíluz (2005) and Tanimoto (2007), each agent imitates the previous action of the individual whose payoff is the highest among neighbors, including herself, in each period. This is called "imitation max". In Fu et al. (2007), each agent x randomly selects her neighbor y to possibly update her action, and imitates y's action with probability $W[s(x) \leftarrow s(y)] = 1/\exp[\beta(P(x) - P(y))]$. Here, the parameter β characterizes the intensity of selection, and $P(z)$ is the sum of the payoffs that agent z received from the PD games with all her neighbors. This is called a "Fermi pairwise comparison". Algorithms like these are usually functions from all the past actions of all subjects that one agent has observed to her current action. Each agent cannot know the functions that the others use, but can observe the actions that the others chose based on those functions. Each agent selects her neighbors based on all the past and current actions of all subjects that she has observed, instead of the structures of these functions.

[4] There are the other simulation studies that use network reciprocity. For example, Tanimoto (2009) assumed three algorithms for creation of links, one being that each agent creates a link to a randomly selected agent from the neighbors of her neighbors instead of the link she dismissed. However, we could not determine if the algorithm our subject used is similar to this algorithm, because we did not provide the subjects with information regarding the neighbors of their neighbor.

[5] The number of links each subject actively dismisses and the links she actively creates are equivalent in each period. As a result, a number of links are limited in the population.

[6] In addition, there are some human-subject experiment studies where subjects play the PD in static networks (e.g., Cassar, 2007; Traulsen, 2010; Grujić et al., 2010). These results show subjects' patterns of action choice in static networks.